Assessment of soil erosion rate and hot spot areas using RUSLE and Multi-Criteria Evaluation Technique: A Case Study at Jedeb Watershed

[1]Tseganeh Getnet and [2]Arega Mulu

[1, 2] Department of Hydraulic and water resources Engineering, Technology Institute, Debre Markos University, Ethiopia

Corresponding Author: Arega Mulu
Email: muluarega21@gmail.com

ABSTRACT

Soil erosion is a difficult forceful practice by which useful surface soil is removed, conveyed, and stored at a detached place causing in the exposure of subsurface soil and siltation in reservoirs and natural streams. The core objective of this study is to evaluate soil erosion rate and to identify soil erosion hotspot areas using RUSLE and Multi-criteria Analysis. Based on the RUSLE model the potential annual soil loss of the watershed ranges from 0.0 to 706.7 ton/ha/yr and the mean annual soil loss rate is 27.7 ton/ha/yr. From the total area of the watershed (859.2 km^2), 63 km^2 are potential areas for gully expansion. The overall analysis indicated that 4.8% of the total watershed is highly sensitive; 54.24% is moderately sensitive; 17.69% is marginally sensitive while, 23.28% is currently not sensitive and the remaining 0.06% was a constraint to erosion. Hence, the Area which is categorized under a highly and moderately sensitive class needs direct mediation for better conservation planning by allowing for known priority classes and hotspot areas.

Keywords: susceptible, GIS, Remote Sensing, RUSLE, MCE, Jedeb watershed

1. INTRODUCTION

Land degradation, a failure in land quality, is a serious threat to the prosperity of the rural population in the world (Eswaran, et al., 2001). Soil degradation by enhanced water erosion is a severe problem and will continue so through the 21st century, mainly in developing countries of tropics and subtropics (Lal, 2001). From the Ethiopia highlands, nearly 1.9 billion tons of fertile soil annually moves by water erosion. This quantity is equivalent to an average soil loss of 130 tons per hectare per year from cultivated lands (FAO, 1986).

The Ethiopian highlands are rigorously affected by soil erosion due to the rapid growth of population, poor cultivation, and land-use practices, deforestation, and overgrazing as well as poor watershed management practices (Lencha and Moges, 2016).

Ethiopia, one of the emerging nations in sub-Saharan Africa, depends on agriculture to assure the demand for food, fiber, and other goods. Nevertheless, diminishing productivity, resulting from the degradation of agricultural land induced by soil erosion, has been and is still a major concern (Teshome et al., 2012). Tamene et al. (2006) indicated that some 50% of the highlands of Ethiopia were already extensively eroded and that erosion was causing an annual decline in land productivity by 2.2%.

Similarly, the Jedeb watershed is characterized by a serious soil erosion problem inducing heavy silt loads in rivers, sheet and inter rill erosion, gully formation and exposed surfaces for erosion on steep slopes is the most visible evidence to show erosion problem. Hence, identification of hot-spot areas of erosion and prioritizing areas for intervention is extremely important for reducing further degradation, reclaiming the degraded areas, and improving the land productivity of the watershed (Lulseged and Vlek, 2005).

Different researches are undertaken to evaluate the rate of soil erosion and mapping erosion risk areas using remote sensing and Geographic information system (GIS) with Revised Universal Soil Loss Equation (RUSLE) formulated by Wischmeier& Smith (1978) and used to estimate the rate of soil erosion and mapping erosion risk areas. For instance, Kirubel and Gebreyesus, (2011) showed the potential of using a combination of remote sensing, GIS, and RUSLE in assessing soil erosion loss on a cell-by-cell basis is very important. Besides, as the erosion method depends on numerous inter-dependent and spatially distributed constraints, the identification of erosion-prone areas is possible using a set of multiple spatially disseminated parameters under a multiple criteria decision analysis (MCDA) to obtain suitable weights which ultimately can suggestion sensitive parts in a watershed. To solve the above-mentioned problems, estimation of soil loss amount using the RUSLE model in GIS and Remote sensing techniques are very important at the watersheds level. And multi-criteria evaluations with the integration of Arc GIS have the ability to rank erosion criteria and analyses spatial information (soil erosion risk areas). The facts on the spatial extent of erosion risk area and its severity are pre-requisites for planning and implementation of the watershed management plans. Therefore, this study is used to provide the respected feedbacks for design soil conservation plans and identifies high-priority areas for the application of best management practices and would play a very important role for the decision-makers, non-governmental organizations as well as experts who will work on soil and water conservation and environmental protections to make their projects in an exact place, cost-effective and well-timed manner.

2. MATERIALS AND METHODS

2.1. DESCRIPTIONS OF STUDY AREA

Jedeb watershed is found in East Gojjam Zone of the Amhara National Regional State of Ethiopia with a geographical coordinate of $10^{0}19'$ to $10^{0}40'$ North and $37^{0}20'$ to $37^{0}50'$ East latitude and longitude respectively as shown in Figure 2.**1**. It is one of the main branches of the Abby River, Ethiopia, which originates from high mountain (Choke) at an elevation of 3996-meter a.m.s.l North East and 1500 meter a.m.s.l in the southwest part of the watershed and drains to the Blue Nile River. Jedeb watershed is found around the northwest part of Debremarkos Town and 302 km far from Addis Ababa and has an area of 859.2 km^2.

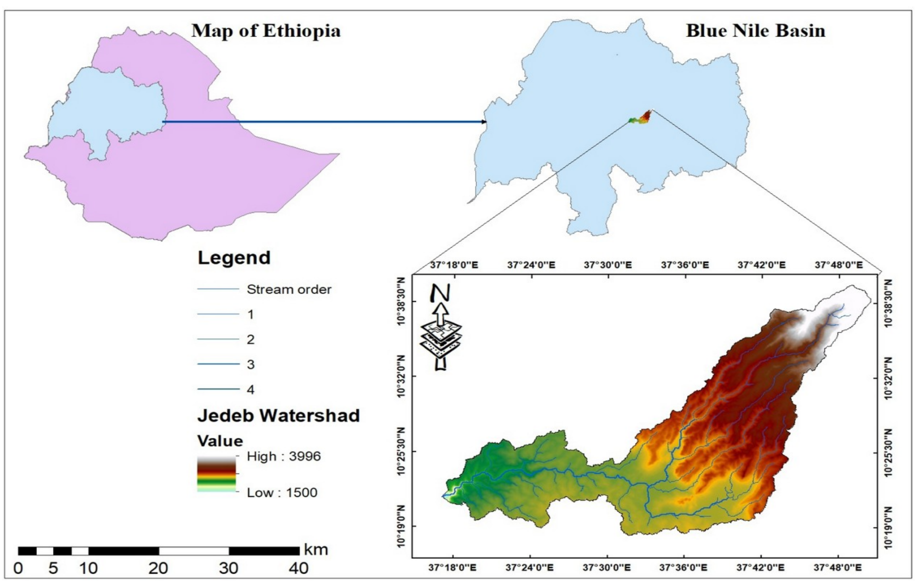


Figure 2.2 Location map of Jedeb watershed

Jedeb Watershed encompasses in three main groups of agro-ecologies which are weyinadega (mid-altitude) and Dega (highland), wurch (Afro_alpin) with a proportion of 81.8%, 17.8%, and 0.43% of total areas respectively distributed.

The main raining period prolongs from June to September. Mostly the dry season occurs between January to March and the remaining months have got partial rain. The long term means annual minimum and maximum temperature of the area varies between 10.44°C and 24.27°C respectively.

2.2. Data source and method of data collection

Daily rainfall data of four stations (Rebugebya, Debremarkos, Dembecha, and Debrealias) from 2000 to 2016 were gathered from the National Meteorological Agency and used to extract rainfall factor maps. Mean annual rainfall data were generated from the monthly rainfall data of 17 years and well adapted for the analysis. The average annual rainfall of the Jedeb watershed ranges from 1303.9 to 1436.9 mm. Digital elevation model (DEM) data are digital representations of cartographic information. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 30-meter resolution developed by NASA was downloaded from the United States Geological Survey and resampled to 12.5m resolution. This DEM was used to demarcate the watershed, to extract information about the topography of the watershed, and to evaluate the drainage arrangements of the land surface terrain using Arc-GIS watershed delineator tools. Another data, Cloud free Landsat 8 OLI/TIRS image, covering the study area were downloaded from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) used for supervised land use land cover classification. Soil data as per FAO soil group were collected and clipped from the Amhara digital soil map which is obtained from the Ministry of Water Irrigation and Energy (MoWIE).

The main soil types identified in this area were Chromic Cambisols, EutricNitisois, Chromic Vertisols Chromic Luvisols, Dystric Nitosols, Eutric Fluvisols, Orthic Acrisols, Lithosols, PellicVertisols. In the Jedeb watershed 53.68% of soil type is dominated by PellicVertisols, and 15.91% Eutric Nitisols distributed in the Southwest part of the watershed. The field data (Gps) collection was done randomly to prove the classified image and to gather the necessary land use/land cover data for accuracy assessment. In addition, to rank, the contribution of the four factors (Topographic Wetness Index, Gully, LULC, and Soil type) for soil erosion informal interview with the natural resource experts and development agents who are working nearby the study area were undertaken and used as an input for pairwise comparison.

2.3. Methods of Data Generation

From DEM data flow accumulation (As) and local slope (β) were created and used an input of, stream power index, and wetness index for determining gully location. Using four spatially distributed erosion hazard parameters (criteria) including Gully, soil erodibility, Topographic wetness Index, and land use Land cover composite erosion index maps were produced and Weighting of decision aspects was allocated based on their comparative influence to erosion practice. Finally, the result of the RUSLE and MCE technique were overlaid for getting the erosion hotspot areas and then prioritizing erosion-prone areas on the watershed as shown in Figure 2.2 flow chart below.

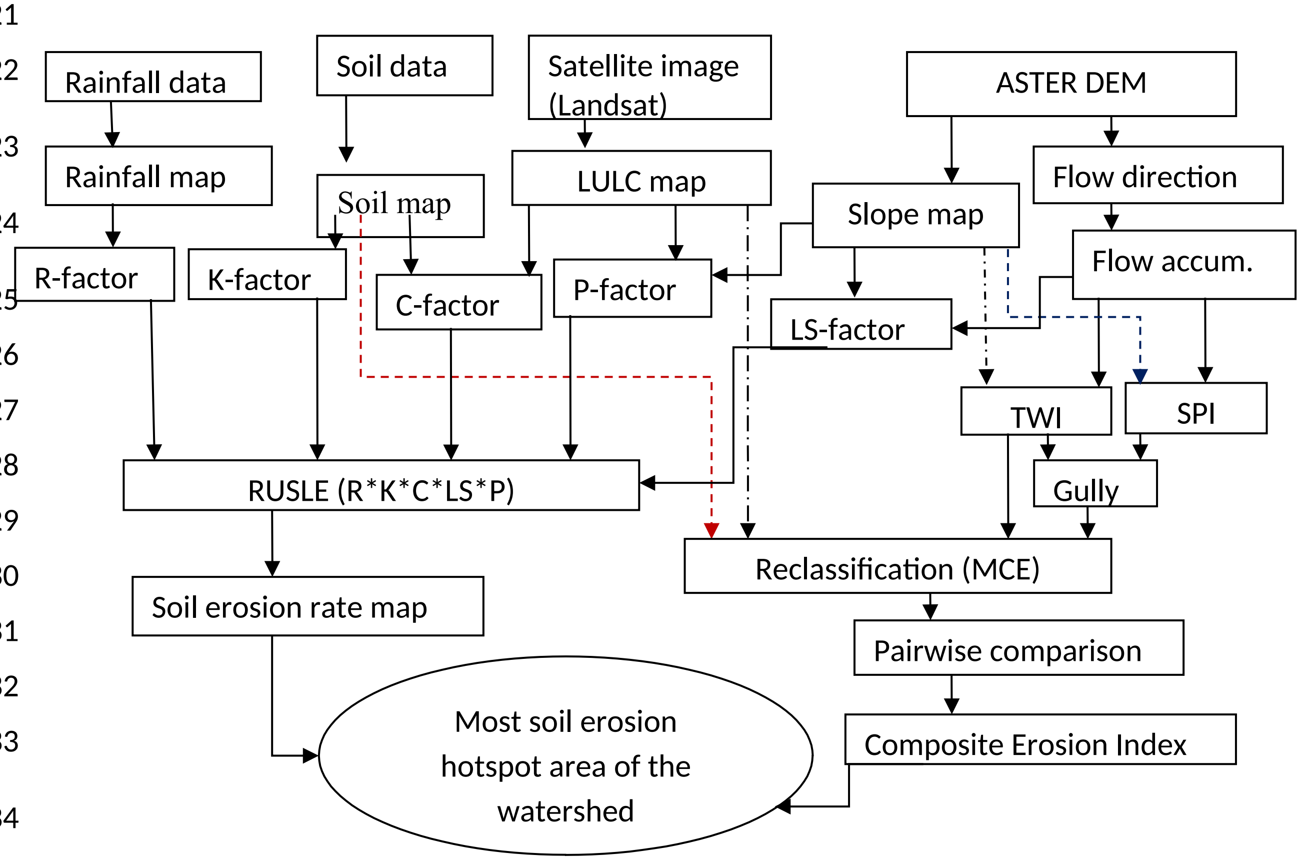


Figure 2.2 Framework of the Methodology Used

Landsat image 8, Bands 4, 3, and 2 are used to combine to make true-color composite images for land use land cover analysis and supervised image classification was done. Which means, the analysts train the computer to recognize

Landsat image 8, Bands 4, 3, and 2 are used to combine to make true-color composite images for land use land cover analysis and supervised image classification was done. Which means, the analysts train the computer to recognize

2.4. RUSLE Factors Generation

The Revised Universal Soil Loss Equation (RUSLE) is an empirically based model that has the capacity to forecast the long term average annual amount of soil erosion on a field slope as a consequence of precipitation arrangement, soil type, topography, crop system, and administration practices (Renard et al., 1997). The RUSLE model in the GIS environment can forecast erosion perspective on a cell-by-cell basis, which is active when trying to categorize the spatial pattern of soil loss existing within a large watershed area (Shi et al., 2004).

The following five factors were used in the RUSLE model to estimate soil loss and expressed as:

$$A=R*K*LS*C*P \qquad (2.1)$$

Where, A is the computed spatial annual soil loss (t/ha/y); R is the rainfall erosivity factor (MJ mm/ h/ ha/y); K is the soil erodibility factor (t /ha/MJ/mm); LS is the slope length and steepness factor (dimensionless); C is the land surface cover management factor (dimensionless), and P is the erosion control or conservation practice factor (dimensionless). For estimating the annual soil loss of the watershed the RUSLE and Arc GIS Raster Calculator tool executes Map Algebra was used.

Rainfall erosivity (R) denotes the erosive power of definite rainfall or the energy of rainfall as the powerful force behind soil erosion (Prasannakumar et al. 2012). R-factor can be described by the collaboration among rainfall kinetic energy with the soil surface (Wischmeier and Smith, 1978). R-factor map can be generated with a raster through interpolation of annual rainfall data using the inverse distance weighting (IDW) method in spatial analysis tool in Arc GIS environment. Thus, the model adopted by Hurni (1985) for the Ethiopian condition is based on the existing mean annual rainfall data (P).

$$\mathbf{R= -8.12+ (0.562*P)} \qquad \mathbf{(2.2)}$$

Where P-Average Annual rainfall and R- rainfall Erosivity factor

Soil erodibility (K) is the essential feature of soil properties gleaming the susceptibility of a soil to erode, as influenced by the biophysical and chemical characteristics of the soil (Renard et al., 1997; Panagos et al., 2015; Fenta et al., 2016). Major soil types were identified and delineated using Arc GIS “Spatial Analyst” tool. Finally, K factor values were assigned from different literature to each soil unit, and the soil erodibility (K) map of the watershed has a grid size of 12.5 m x12.5m was made with adopted K values. The K value varied from 0 to 1, where the previous propose less and the future indicates high vulnerability to erosion risk, correspondingly (Farhan and Nawaiseh, 2015).

Topographic factors (LS): In RUSLE, Slope length is demarcated as the horizontal distance from the beginning of overland flow to the point where deposition initiates or where runoff flows into a defined channel (Renard et al*.,* 1997). The influence of the topography aspect on soil erosion amounts is stated by the joint influence of slope length (L) and slope steepness

(S) on rill, inter-rill erosion, and sediment creation. As slope length increases (L), the total soil erosion loss per unit increases, as a result of the progressive accumulation of runoff in downslope. As the slope steepness increases, the soil erosion also increases as a consequence of growing the velocity and erosivity of runoff (Wischmeier and Smith, 1978). Rill erosion is mostly initiated by surface runoff and increases in a downslope direction because of the runoff increases in this direction. interracial erosion is the result of the raindrop effect on the soil surface and is considered uniform along a slope (Pradhan et al., 2012). The L factor states the ratio of rill erosion (initiated by flow) to inter-rill erosion (raindrop impact) to find the loss of soil in relative to the usual plot length of 22.1 m and the slope steepness parameter (S) relays to the consequence of the slope gradient on erosion in relation to the normal plot steepness of 9^{o} (Wischmeier and Smith, 1978). With the intention of originating LS-factor values, a series of DEM derived grids are made using Arc GIS. Any spurious single-cell sinks within the source DEM are filled to create a depression less DEM, using filled DEM flow directions and accumulation was determined. Based on flow accumulation and slope steepness LS factors were computed using Raster Calculator in Arc GIS.

LS=(("Flow Accumulation"*cell size/22.1) ^0.6)*((Sin ("Slope)*0.01745)/0.09)^1.4) (2.3)

Where, LS is slope steepness and slope length factor.

Land cover factor (C): Surface cover disturbs erosion by reducing the transportability of excess water and by decreasing the surface area vulnerable to raindrop influence (McCool, 1995). Increasing surface roughness decreases transport capacity and detachment of runoff by reducing flow velocity. Satellite images are used to determine the C-factor by land cover classification (Folly et al., 1996). The C-factor is defined as the fraction of soil loss from land with definite vegetation to the equivalent soil loss from continuous fallow with the same rainfall (Wischmeier and Smith, 1978). From the Supervised digital image LULC classification, the Cover factor C-value was allocated from different texts for each land-use class using the "reclass" system in Arc GIS. In this study C factor for each land use/ land cover was accustomed to creating a cover factor map as an input for RUSLE.

The management practice factor (P) indicates the consequence of conservation follows on soil erosion, where in the land which has adequate conservation interventions. This study engaged a different technique spending a combination of slope and land use/covers for valuation of the P-value as suggested by Wischmeier and Smith (1978) and other related revisions by Hurni (1985), Bewket and Teferi (2009), Gelagay and Minale (2016). In this study area, there is only a small area that has been preserved with terracing over the agricultural extension program of the government and poorly maintained as implementation was made without the contribution of the indigenous people. Hence, the whole study area is not preserved with better stable soil and water conservation processes. Since data were missing on permanent administration aspects and there were no management practices, we used the P-values recommended by (Bewket and Teferi, 2009, Wischmeir and Smith, 1978) that considers only two types of land use (agricultural and non-agricultural) and land slopes. Values for this factor were allocated between 0 and 1 by considering local management practices.

2.5. Evaluation of erosion criteria for Multi-criteria decision analysis

MCDA suggests the assignment of standards to options that are assessed along with multiple decisions or criteria (Kumar et al., 2015). As erosion practice hangs on numerous inter-dependent and spatially disseminated issues, the identification of erosion-prone areas is potential by a set of multiple spatially disseminated factors or constraints under an MCDA to get appropriate weights which eventually can suggestion sensitive areas in a watershed. The Analytic Hierarchy Process (AHP) is the most usually used MCDA tool that uses hierarchical structures to characterize a problem and then develop priorities for the options based on the decision of the user (Saaty, 1980). For this study MCE techniques within the GIS, the environment recognized the real source of erosion and mapped sensitive areas based on spatial dataset investigation. An effort has been made to isolate the appropriate sub-watersheds for soil conservation methods using five spatially distributed erosion hazard factors together with soil loss using the RUSLE model, soil erodibility, Gully, Topographic wetness Index, and land use Land cover was used. Maps of each criterion were classified based on literature results (Lulseged & Vlek, 2005; Assefa et al., 2015).

The weight of decision aspects is allocated based on their comparative consequence to the erosion practice. Each standard was presented and stored in the layer by using Arc GIS and their values were produced. If the Consistency ratio is less than 10 %, established the decisions are reliable. Finally, each criterion was Re-classified based on their sensitive class from FAO (1981) as shown in Table 2.2.

Table 2.2 soil erosion sensitivity class (FAO, 1981)

Sensitivity classes	ID	Justification
Highly sensitive	S1	Factors significantly accelerate erosion
Moderately sensitive	S2	Factors clearly sensitive but has the opportunity to reduce
Marginally sensitive	S3	Factors significantly reduce erosion
Currently not sensitive	S4	Factors that cannot support erosion

Topographical wetness index (TWI) criteria: it is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction (Lencha and Moges, 2016). The TWI gives the spatial distribution and zone of saturation sources for overflow generation.

Stream power index criteria (SPI): it is the degree of energy of flowing water which is applied on the bed and bank of a channel. SPI is a quantity of the erosive power of water flow based on the theory that release is relative to the definite catchment area (As). TWI and SPI have been calculated based on the technique followed by Moore et al. (1991).

$$\mathbf{TWI=\ln[As/\tan(\beta)]} \quad \mathbf{(2.4)}$$

$$\mathbf{SPI=\ln(As\times\tan(\beta))} \quad \mathbf{(2.5)}$$

Where; As is the specific catchment area in meters and **β** is the slope gradient in degrees.

Both stream power index and wetness index were determined using the Arc GIS Spatial Analyst raster calculator.

Potential locations of ephemeral Gullies and their effects on soil erosion

Ephemeral gullies are the “missing link” between rills and permanent waterways (Thorne et al.,1986). A gully catalog plot was established in order to calculate the density of the gully areas for each class of the affecting aspects**.** For establishing the potential location of the gully; first, the upslope contributing area or flow accumulation (As) and local slope (β) were made from DEM of the study area. The thematic maps made for each predisposing factor SPI and TWI have been converted into raster format through Arc GIS. As stated by Tebebu et al. (2010), Simon et al. (2011), and Zegeye et al. (2014) gullies are the most significant contributor for soil erosion on the watershed. The potential locations and sensitivity of a specific field of gullies formation were forecast when the resulting two situations of the thresholds SPI >18 and TWI >6.8 were satisfied (Lulseged and Vlek, 2005). In general, the gully incision is probable to appear when a causative area together with local slope exceeds a given threshold (Jettenet al., 2006). For different environmental situations and different gully introducing procedures, different thresholds were applied (Poesenet al*.,* 2003).

2.6. Pairwise comparison

Subsequent to generating the criteria maps of soil erosion, transforming the factors into a standard scale of measurement was mandatory. For assigning weights in this study, the pairwise comparison method was used so as to reduce the complexity of decision making since two components are considered at a time. This is because a multi-criteria decision analysis technique requires the evaluation criteria to be standardized to corresponding units since each criterion map contains raw values.

The Analytic Hierarchy Process: The Saaty‟s Analytic Hierarchy involves defining the unstructured problem, developing AHP hierarchy, pair-wise comparison, computation of relative weights, consistency check and finally obtaining an overall rating for obtaining desired results (Lee et al, 2008). If different erosion hazard parameters are scaled as 1 to 9, 1 indicates that the two factors equally important, and 9 indicated that the one factor is more important than the others. Reciprocal of 1 to 9 (1/1 and 1/9) shows that one is less important than others. To fill the comparison matrix, using Saaty's fundamental weighting scale, the contribution of erosion factors (land use/ land cover, Topographic wetness index, gully, soil type) for soil erosion, informal interview with the natural resource experts were performed and used as an input for pairwise comparison. From the comparison matrix, the priority vector is computed and the normalized eigenvector of the matrix is used to assign the weight for different factors based on their relative effect on erosion. Soil erosion factor maps were generated and reclassified based on their sensitivity classes. Based on the factors final weight, the reclassified maps were overlaid to obtain the combined effect of all factors and produced the final soil erosion hotspot area map of Jedeb watershed.

3. RESULTS AND DISCUSSION

Land use/ Landcover

In this study, the land cover map was prepared based on supervised classification by selecting the training sites which are typically representative of the land cover classes.

Analysis of the 2019 land sat satellite image revealed that intensively and moderately Cultivated Land constituted the largest proportion of land in Jedeb Watershed with a value of 57.7%, followed by grass and bushlands with 22.3%, and 12.6% coverages respectively. Bare land and water cover small percentages, i.e 1.7%, and 0.1% respectively (Figure 3.1).

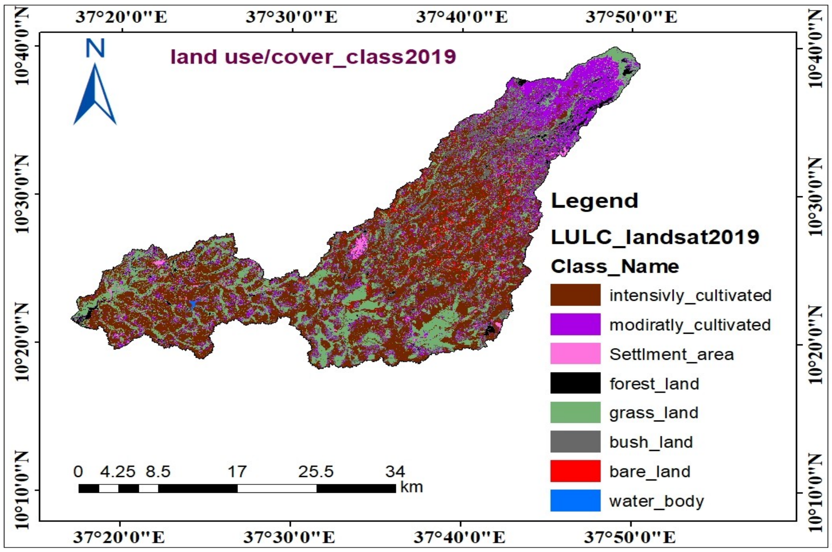


Figure 3. 1 Land use/cover map of the study area (2019)

Potential soil loss on the Jedeb watershed

The result of the RUSLE Model showed that the potential annual soil loss of the Jedeb watershed ranges from 0.0 to 706.7 ton/ha/year. The mean annual soil loss rate of the whole study area is 27.7 ton/ha/year; which is much greater than the tolerable level 10 ton/ha/year (Hurni, 1983) but has an Acceptable value according to Gete, et al. (2014) using an empirical approach, which found about 73% of the Abbay basin has soil loss that is less than 30 ton/ha/yr. Based on different soil erosion literature on the Blue Nile Basin (Haregeweyn et al.,(2017); Bewket & Teferi, (2009)), the results of this study were classified into five major severity classes. These classes indicated that those above 100 ton/ha/year were categorized as severe soil erosion risk which covers 2.98% of the total area, and 14.32% of the watershed areas were classified as very high (50 to 100 ton/ha/year) soil erosion risk zones, almost one-fourth (24.9%) of the study area is characterized as high soil erosion rate (25 to 50 ton/ha/year). While 57.79% of the watershed which is below 25 ton /ha/year was categorized as low to moderate levels of soil loss. High to severe soil erosion risk occurred in the Northeastern parts of the watershed and it is greater than 2307 m in elevation (more than 1/3rd (361.9 km^2) of the total surface area due to steep slope and rugged landforms of the watershed).

Validation of the Model Estimate

Validation of the model estimates was challenging in this study due to poorly available data to evaluate against the model estimates with the actual soil loss. However, as an option hydrological scientific model validation methods proposed by Biondi et al. (2012) was used to check the validity and consistency of the model estimation by comparing it with that of previously published results (Haregeweyn et al., 2017 and Zerihun et al., 2018). The result was compared against studies conducted in the nearby areas mainly Northwestern highlands with both observed (Gelagay and Minale 2016; and Subhatu et al. 2017) and estimated results. Some variations on previously reported results with this study estimates could be related to their respective site-specific variations in parameters. Consistency of the model estimate is related with previously published results in the Upper Blue Nile Basin, northwestern highland (Haregeweyn et al. (2017) for terraced upper Blue Nile basin (27.5 ton/ha/year), Gelagaye & Minale (2016) for Koga watershed was 47.4 ton/ha/year and Estifanos (2014) for Rib Watershed (39.8 ton/ha/year)). And also Setegn et al. (2010) reported a relatively comparable estimate for Anjeni Watershed was (24.6 ton/ha/year). The result of this study was somehow higher than the estimates for the Geleda watershed and Mojo watershed which is 23.7 ton/ha/year and 21.2 ton/ha/year respectively. On the other hand, relatively higher soil loss was reported by Shiferaw (2018) 78.6 ton/ha/year for the Chemoga watershed. This could be recognized to partially lowland and gentle slope conditions together with relatively lower rainfall on Jedeb watershed. Generally in the Ethiopian highland case erosion rate ranging from 2 up to 18 ton/ha/year is believed to be tolerable according to modified Hurni (1985).

Preparation of erosion Criteria Maps

Each factor (topography, potential locations of gullies, land use, and soil) was reclassified based on sensitivity classes. Finally, each map was then overlaid so that each pixel in that map had the sum of the four map values based on sensitivity classes.

3.1. Impact of Land use/cover on erosion

Land use map is one of the most important factors that affect surface runoff and erosion on a watershed. It controls the detachability and transport of soil particles and the infiltration of water into the soil. So it enables to assess the resistance of terrain unit to erosion as a result of surface protection. According to Tewodros et al.,(2015) land use land cover sensitivity class of this LULC was classified into four categories and shown in Table 3.1.

Table 3.1 LULC sensitivity class

Land use/cover Type	Erosion Sensitivity Class	Area (km^2)	% coverage
Forestland, Grassland	Low (S4)	211.46	24.61
BushLand	marginal (S3)	108.63	12.64
Cultivated land, Settlement	Moderate (S2)	524.44	61.04
Bare land	high (S1)	14.18	1.65

These sensitivity classes indicated that 1.7% of the land use is highly sensitive; 61% moderately sensitive; 12.64% marginally sensitive; 24.61% currently not sensitive and about 0.06% constraint to erosion and also shown in Figure 3.2.

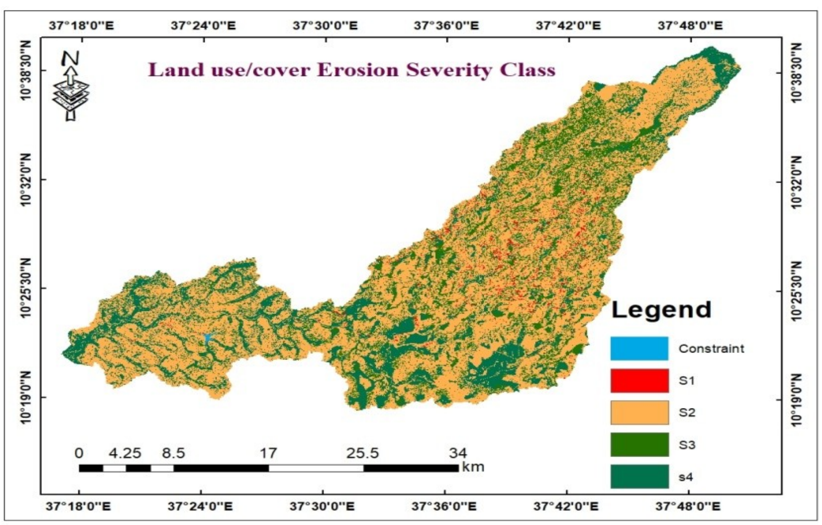
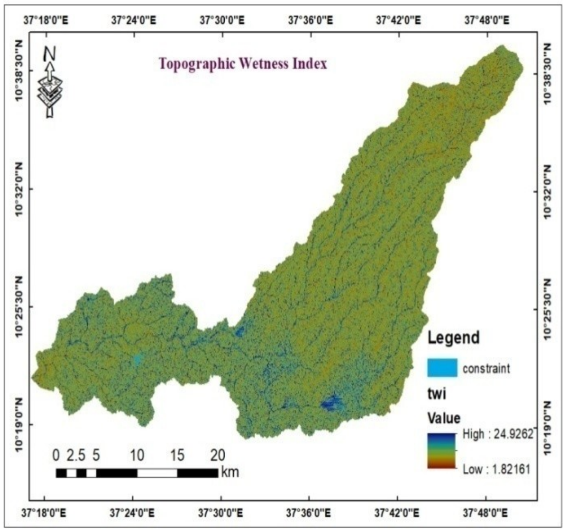


Figure 3.2 LULC sensitivity map

3.2. Topographic wetness index effect on erosion

Topography which determines the saturated excess runoff generation over the land represented with TWI. The topographic wetness index of the catchment was predicted based on flow accumulation and slope of the particular pixel. As the contributing area increase and the slope gradient decreases, the topographic wetness index and soil moisture increase, it has a higher correlation with saturation (Easton et al., 2010). Figure 3.3 presented the topographic index map and Erosion sensitivity class for TWI offered in Table 3.2 and reclassified TWI map is shown in Figure 3.4.



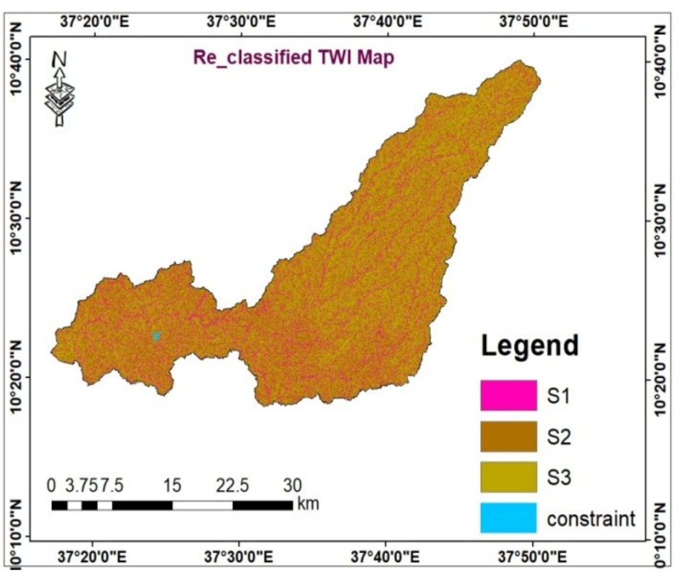


Figure 3.3 Topographic Wetness Index map Figure 3.4 Reclassified TWI map

Table 3.2 TWI sensitivity class

Rank	TWI class	Erosion Sensitivity Class	Area(km^2)	% coverage
1	<5.9	marginal (S3)	401.57	46.7
2	5.9_11.5	Moderate (S2)	430	50.0
3	>11.5	high (S1)	27.15	3.3

The reclassified TWI map (Figure 3.3) indicated that 3.3% is highly sensitive; 50% moderately sensitive; 46.7% marginally sensitive and about 0.06% constraint to erosion. Based on this the southwestern part of the watershed was more saturated but the North-Eastern part of the watershed was less saturated, resulting highly and slightly sensitive to soil erosion respectively. So Areas prone to water accumulation (large contributing drainage areas) and characterized by low slope angles were linked to high TWI values. On the other hand, well-drained dry areas (steep slopes) are associated with low TWI values.

3.3. Effects of gullies on erosion

To predict potential spatial patterns of ephemeral gullies in the area, stream power index and Topographic wetness Index above threshold values were estimated using the ArcGIS raster calculator using the expression: "SPI> 18 and TWI > 6.8". The SPI and TWI values ranged from 0 to 17.45 and 1.8 to 24.9 respectively. The higher SPI and TWI values indicated that it has a higher correlation with the formation of a gully. As the causative area increases and the slope gradient decreases, the topographic wetness index and soil moisture increases. And as SPI increases, the contributing area, and the slope increases. For various environmental circumstances and different gully initiating processes, different thresholds can be applied. Gullies are mapped from Google earth and the potential location is then up to the stream power index value of 11 and TWI greater than 6 which can be taken as a threshold value of gully prone area for this watershed. For validation, gully location maps were crossed with 37 ground control points as illustrated in Figure 3.5 and using the Contingency matrix with the overall accuracy of 78.4 % for predicting potential gully locations. This result explained that SPI and WI with the threshold values 11 and 6 respectively seemed to be somewhat acceptable for predicting potential areas for ephemeral gully location in the area. The resulted map showed that areas with values S3 and S1 are with no gully and with gully erosion respectively.

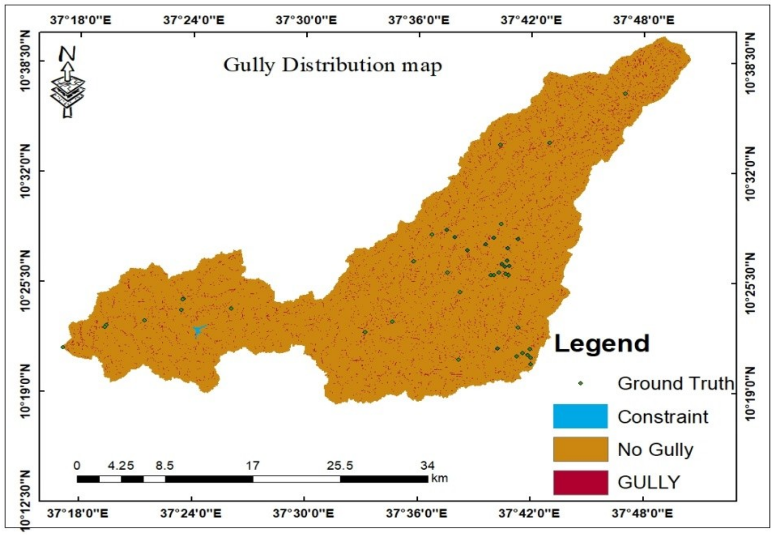


Figure 3.5 Potential gullies map

Based on the result obtained from the reclassified gully potential sensitivity map of Jedeb watershed (Figure 3.5) about 92.67% (796.2 km^2) of the area is with no gully and the remaining 7.33% (63 km^2) is with gully erosion and 0.06 % were constraint (water body) to soil erosion.

3.4. Impact of soil type on erosion

Soil type is one of the significant aspects that affect the erosion procedure and controls the detachability of soil, soil particle transport mechanism, and infiltration of water into the soil (Setegnet al., 2009). After assigning values for each soil type, the soil map was reclassified using adopted K values with a grid map of 12.5 m-cell sizes. The watershed is dominated by PellicVertisols (53.68%) followed by Eutric Nitosols (15.91%) which has moderately well drainage classes. The reclassified soil map shows that 29.52% of the soil (Dystric Nitosols, Orthic Acrisols, Chromic Luvisols, Eutric Nitosols) were highly sensitive; 3.66% of total soil types (Chromic Camboisols and Eutric Fluvisols) were moderately sensitive; (Lithosols, Chromic Vertisols, Pellic Vertisols) 66.76% of the total were marginally sensitive and the remaining (0.06%) is a constraint to erosion.

The Collective outcome of MCE Techniques

3.5. Weighting using Pairwise comparison

Every principles layer was found from MCE factor generation and reclassification and then multiplied by the corresponding weight resulting from a pairwise comparison of criteria. Since the gully formation is the combined effects of all major factors (Topographic wetness index, soil saturation index, and land use land cover) and based on an informal interview with the natural resource experts, the first rank was given to gully formation and measured as a highly important factor, while soil type was considered as the least important element. The dependability of weights was checked by computing the consistency of the comparison matrix which originated reliable. The value of Principal Eigenvalue (λmax) and consistency index (CI) has been estimated as 4.044 and 0.015 respectively. As per four erosion exposure factors that have been considered in the decision, the random consistency index (RI) comes out to be 0.9. The consistency ratio for the present conclusions has been calculated as 0.016264 which is less than 0.1. The Consistency Ratio of <0.1, is considered satisfactory and, therefore, the pairwise weights were accepted for further MCA to calculate erosion intensity in the area.

Table 3.3 Pairwise comparison matrix

Criteria	Gully	Land use/Cover	TWI	Soil	Weight %
Gully	1	2	5	7	51.63
Land use/Cover	½	1	4	5	31.89
TWI	1/5	¼	1	2	10.24
Soil	1/7	1/5	½	1	6.24

Based on the results obtained from the Pairwise comparison matrix Techniques the four criteria (Gully, Land cover, TWI, and Soil); Gully (51.63%) has a high contribution to soil erosion. While, LULC (31.89%), TWI (10.24%), and soil (6.24%) have second, third, and fourth respectively in contributing to soil erosion in the area.

3.6. Erosion Intensity with Respect to Composite Erosion Index (CEI)

CEI relates to the erosion strength of the unit area under the comparative input of a given criterion (Saptarshi & Raghavendra, 2009). Finally, the effect of four weighted criteria was overlayed in Arc GIS in spatial analyst tool raster calculator by an appropriate weight derived from pairwise comparison criteria (Table 3.3)

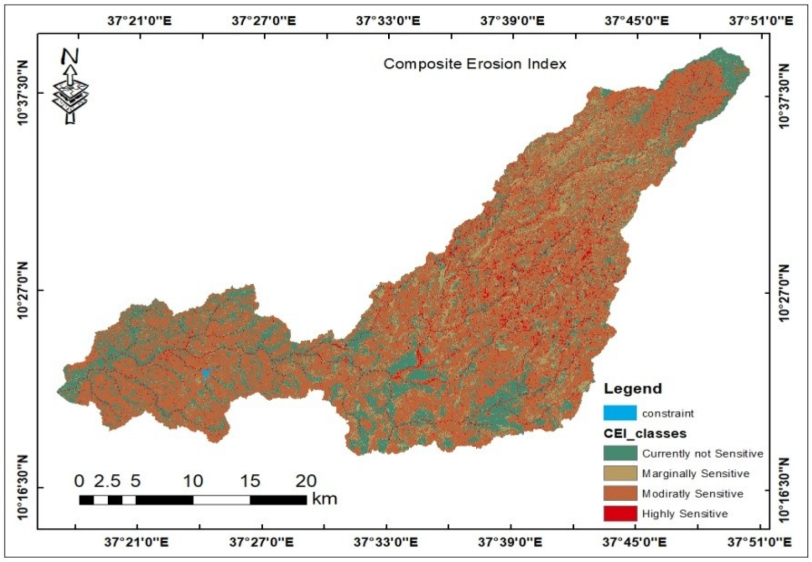


Figure 3.6 Composite Erosion Index map

Based on sensitivity classes, the erosion source map (Figure 3.6) indicated that 3.45% of the total watershed is highly sensitive; 59.66% is moderately sensitive; 13.17% is marginally sensitive while, 23.06% is currently not sensitive and the remaining 0.06% of the watershed is a constraint to erosion. This specified that the main cause of erosion is the high land area of the catchment.

Overall soil erosion source and Prioritization

The result of the overall soil erosion hazard map specified that 4.8% of the total watershed is highly sensitive; 54.24% is moderately sensitive; 17.69% is marginally sensitive while, 23.28% is currently not sensitive and the remaining 0.06% was a constraint to erosion.

To get the combined final soil erosion sensitivity area the soil loss map and multi-criteria evaluation sensitivity map were categorized into four equal classes and have been overlaid based on weighted overlay analysis as shown in Figure 3.7.

Therefore, the combination of both methods was applied for soil erosion assessment to obtain the most sever sites to soil erosion and grouped into four soil erosion source classes based on their mean and standard deviation in the ArcGIS environment as shown in Table 3.5.

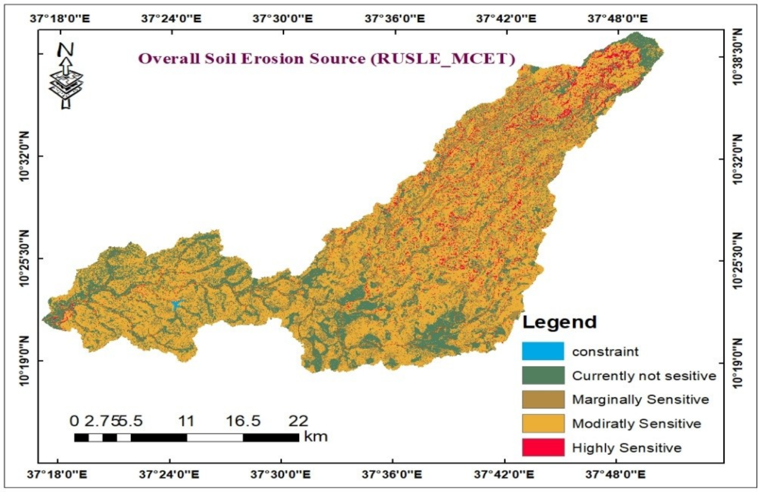


Figure 3.7 Overall soil erosion hazard map

Table 3.5 prioritization of sub watershed based on RUSLE-CEI

Erosion Risk Class	Mean RUSLE-CEI	Sub-watersheds (ID)	Priority Level	Area (km^2)	Percent Coverage
Low	1.702-2.194	13, 14, 25,23,24	IV	302.44	35.2
Moderate	2.267-2.499	17, 18, 19, 21, 22, 2, 1	III	175.98	20.48
High	2.512-2.584	20, 16, 12, 10, 5,	II	123.45	14.37
Very high	2.593-2.70	6, 7, 9, 11,15,3	I	257.34	29.95

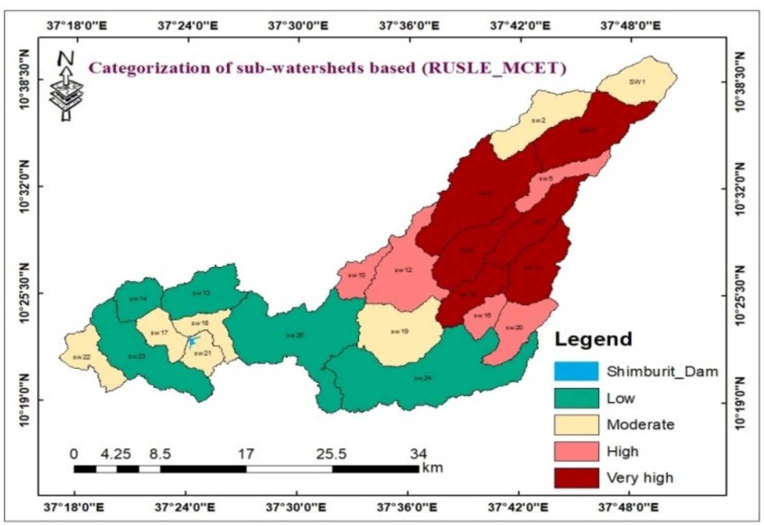


Figure 3.8 Subwatershed prioritization map

As a result, the critical sub-watersheds were ranked, presented, and recommended for sub-watershed treatment in order to decrease the probable soil losses and to protect the natural resources within the watershed. As the result of this study, the top priority for soil conservation measures must be given to sub-watershed (SW6, SW7, SW9, SW11, SW15, SW3), in the first stage, sub-watersheds (SW20, SW16, SW12, SW10, SW5,) considered in the second stage, whereas sub-watershed (SW17, SW18, SW19, SW21, SW22, SW2, SW1) and (SW13, SW14, SW25, SW23, SW24) are considered in the 3rd stage and the fourth stage respectively and shown in Figure 3.8 above.

Conclusion

This study attempts to evaluate the actual average of annual soil loss rate and identified erosion hot spot areas of Jedeb watershed by using RUSLE and MCE techniques as well as Arc-GIS. By using supervised image classification, the study areas were classified into eight land use land cover classes. On the base of their cover factor, bare land covered 14.2 km^2 of an area that is highly susceptible to soil erosion. Next intensively cultivated lands that covered the largest portion of the area (380.8 km^2) are sensitive to soil erosion. Based on the RUSLE, the estimated potential erosion varied from 0 to 706.7 ton/ha/yr. The mean annual potential soil loss from the entire watershed was found to be 27.7 ton/ha/yr. Prediction of a potential location for gully formation using the concept of the Topographic threshold indicated that 63 km^2 (7.33%) of the areas are with gully potential and about 796.2 km^2 (92.7%) of are with no gully formation. while the rest (0.1 %) is a constraint (water body) to soil erosion. Most of the ephemeral gullies were found in agricultural areas and in bare lands. The research also has tried to prioritize the sub-watersheds based on the average annual soil erosion rate and composite erosion index (RUSLE and MCE). The result of (RUSLE-MCE) overall soil erosion indicated that 4.8% of the total watershed is highly sensitive; 54.24% is moderately sensitive; 17.69% is marginally sensitive while, 23.28% is currently not sensitive and the remaining 0.06% was a constraint to erosion.

Data availability Statement

Some of the data which are used for this work are found with is the corresponding auther linked with in the **Data Availability**

Recommendation

Based on the result of this study, the sub-watersheds which have fallen under very high and high severity classes need immediate attention in their prioritization of soil erosion.

Therefore, the concerned organizations and the regional government offices should take care of the area from further soil erosion through Creating awareness among the society about the sustainable use of natural resources and conservation methods.

REFERENCES

Assefa, T.T., Jha, M.K., Tilahun, S.A., Yetbarek, E., Adem, A.A., Wale, A., 2015. Identification of erosion hotspot area using GIS and MCE technique for Koga watershed in the Upper Blue Nile Basin, Ethiopia. Am. J. Environ. Sci. 11 (4), 245.

Biondi, D., Freni, G., Iacobellis, V., Mascaro, G., Montanari, A., 2012. Validation of hydrological models: conceptual basis, methodological approaches, and a proposal for a code of practice. Phys. Chem. Earth Parts A/B/C 42, 70–76. http://dx.doi.org/10. 1016/j.pce.2011.07.037

Estifanos, A., 2014. Assessment of Micro-Watershed Vulnerability for Soil Erosion in Ribb Watershed Using GIS and Remote Sensing. MSc Thesis. Mekelle University.

Eswaran, H., Lal R., and Reich. P.F. (2001). Land degradation: an overview. In: Bridges, E.M., Hannam, I.D., Oldeman, L.R., Penning de Vries, F.W.T., Scherr, S.J., and Sompatpanit, S. (eds.). Responses to Land Degradation. International Conference on Land Degradation and Desertification. New Delhi, India.

Bewket W, Teferi E (2009). Assessment of soil erosion hazard and prioritization for treatment at the watershed level: a case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land Degrad Dev **20**:609–622

Demesew A. Mhiret, Dessalegn C. Dagnew, Tewodros T. Assefa, Seifu A. Tilahun, Benjamin F. Zaitchik, Tammo S. Steenhuis (2018). Erosion hotspot identification in the sub-humid Ethiopian highlands. pp 147 – 1547

Farhan Y, Nawaiseh S (2015) Spatial assessment of soil erosion risk using RUSLE and GIS techniques.Environ Earth Sci 74(6):4649–4669. https :// doi.org/10.1007/s1266 5-015-4430-7

Fenta AA, Yasuda H, Shimizu K, Nigussie H, Negussie A (2016) Dynamics of soil erosion as influenced by watershed management practices: a case study of the Agula watershed in the semi-arid highlands of northern Ethiopia. Environ Manag 58:889–905

Food and Agricultural Organization. (1981). Guidelines for designing and evaluating surface irrigation systems. Irrigation and Drainage Paper 45. FAO (Food and Agricultural Organization of the United Nation, Rome

Food and Agriculture Organization. (1986). Ethiopian highlands reclamation study, Final Report (Volume II), Food and Agriculture Organization (FAO) Rome

Gelagay, H.S., Minale, A.S., (2016). Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. Int. Soil Water Conserv. Res. 4, 126–136

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J., Adgo, E., 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: a case study of the Upper Blue Nile River. Sci. Total Environ. 574, 95–108.

Hurni, H., (1985). Erosion productivity conservation systems in Ethiopia. IV. International Conference on Soil Conservation, Venezuela, 20.

Lencha, B., and Moges, A. (2016). 'Identification of Soil Erosion Hotspots in Jimma Zone (Ethiopia) Using GIS-Based Approach', (June). DOI: 10.4314/ejesm.v8i2.7S. Of, A. et al. (2014) 'Mekelle university'.

Lal, R., (2001). Soil conservation for C sequestration. In: Stott D.E, Mohtar RH, Steinhardt G.C (eds) Proceedings of the 10th international soil conservation organization meeting, 24–29 May 1999, West Lafayette.

Lulseged, T. and Vlek, G.L.P. (2008). Soil Erosion Studies in Northern Ethiopia. Springer Science Business Media B.V

Lulseged,T., Vlek, P.L.G., 2005. GIS-based landscape characterization to assess soil erosion and its delivery potential in the highlands of northern Ethiopia. 7–9 September, Trier, Germany, Proceedings of the 1st International Conference on Remote Sensing and Geoinformation Processing in the assessment and monitoring of land degradation and desertification 332–339.

McCool DK, Brown LC, Foster GR. (1987). Revised slope steepness factor for the universal soil loss equation. *Trans Am Soc Agric Eng*. **30**:1387−1396.

Moore, I. D, Burch, G.J. and Mackenzie, D.H. 1988. Topographic effects on the distribution of surface soil water and the location of ephemeral gullies. 31(4),1098-1107.

Panos Panagos, Pasquale B.and Katrin M, (2015), A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water, Journal of Geosciences, **5**: 117-126;

Prasannakumar V, Vijith H, Abinod S, Geetha N (2012) Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. Geosci Front 3:209–215

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion By Water: A Guide To Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703. Agricultural Research Service, Washington, DC.

Subhatu A, Lemann T, Hurni K, Portner B, Kassawmar T, Zeleke G, Hurni H (2017) Deposition of eroded soil on terraced croplands in Minchet catchment, Ethiopian Highlands. Int Soil Water Conserv Res 5:212–220. https :// doi.org/10.1016/j.iswcr .2017.05.008

Tamene, L; S.J. Park; R. Dikau; P.L.G. Vlek. (2006). Reservoir Siltation in Ethiopia: Determinants, Source Areas, and Management Options. In UNESCO-Chair in Water Resources proceeding of international sediment initiative conference, 12-15 Nov. 2006, Khartoum, Sudan.

Thorne, C.R., Zevenbergen, L.W., Grissinger, E.H., Murphey, J.B., 1986. Ephemeral gullies as sources of sediment. March 24–27 Las Vegas, Nevada Proceedings of the Fourth Federal Interagency Sedimentation Conference, vol. 1.

Saaty, T.L., (1977). A scaling method for priorities in hierarchical structures. J. Math. Psychol., 15: 234-281. DOI: 10.1016/0022-2496(77)90033-5

Saaty T. L. (2008) Decision making with the analytic hierarchy process, International Journal of Services Science1, 83 98.

Setegn, S.G., R. Srinivasan, B. Dargahi, and A.M. Melesse, (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. Hydrol. Processes, 23: 3738-3750.DOI: 10.1002/hyp.7476

Shi, Z.H., CAI, C.F., Ding, S.W., Wang, T.W., and Chow, T.L. (2003). Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China. Catena 55, 33-48.

Tamene, L. and Vlek, P. L. G., (2007). Assessing the potential of changing land use for reducing soil erosion and sediment yield of catchments: a case study in the highlands of northern Ethiopia.

Wischmeier, W.H., and. Smith D.D., (1978). Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook No. 537, US Department of Agriculture, Washington DC.

Zegeye, A.D., Amare, S.D., Tilahun, S.A., Langendoen, E.J., Dagnew, D.C., Guzman, C.D., Tebebu, T.Y., Steenhuis, T.S., 2014. Gully development processes in the Ethiopian highlands. In:

Proceedings of the second International Conference on the Advancements in Science and Technology (ICAST)Bahir Dar University, pp. 220–229.

Zerihun, M. Yasin, Y. Sewnet, D.Anwar A. Lakew, M. (2018). ‘Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia, pp.85-89’